

DEVELOPMENT OF BATTERY IMPEDANCE TESTER

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ABSTRACT

Introduces an applicable method for measuring battery's internal impedance and conductance techniques have been advocated in the determination of the condition of lead-acid batteries in service. The battery itself has an internal resistance that makes it difficult to control the charging and discharging process because the capacity of the battery is estimated by the potential difference between the two electrodes of the battery, named external voltage. The usefulness of these "ohmic" techniques lies in an understanding of the bounds and domain of the measurement. Impedance model contains a lot of information that can indicate performance of battery. Therefore, establishment of accurate impedance model is very important. The impedance behaviour during individual discharge cycles as well as over its cycle life is obtained. Frequency response and battery impedance behaviour generally observed for a of commercially available batteries. The impedance is calculated by the ratio of voltage and current variation.

ABSTRAK

Memperkenalkan dan mengaplikasi cara bagi teknik mengukur kerintangan dan kearuhan dalam bateri yang dikenal pasti dengan didalam lead acid bateri. Dalam bateri sendiri mempunyai kerintangan dalaman yang membuatkan ianya sukar untuk mengawal process mengecas dan proses mengenyahcas kerana kapasiti bateri yang dijangka oleh perbezaan potensi berbeza di antara dua elektrod pada bateri. Yang dikenali sebagai voltan luaran. Kegunaan teknik ohmic adalah bagi memahami ikatan dan domain pada pengukuran. Model kerintangan mempunyai banyak maklumat yang boleh menunjukkan prestasi bateri. Kerintangan model yang tepat amat penting. Sifat kerintangan sewaktu keadaan mengenyahcas adalah lebih besar dari keadaan jangka hayat bateri. Frekuensi respon dan sifat kerintangan bateri secara keseluruhannya dilihat bagi julat secara komersial. Kerintangan dikira berdasarkan oleh nisbah variasi arus dan voltan

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LIST OF ABBREVIATIONS

DC	-	Direct current
ESL	-	Effective Series Inductance
ESR	-	Equivalent series resistance
PCB	-	Printed circuit board
CCM	-	Continuous current mode
IC	-	Integrated circuit
V_{in}	-	Input voltage
V_o	-	Output voltage
V_{ramp}	-	Ramp voltage
V_{error}	-	Error voltage
V_{switch}	-	Switch voltage
D	-	Duty cycle
T_s	-	Switching period
f_s	-	Switching frequency

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CHAPTER 1

1.0 Introduction

In recent years there has been considerable activity and debate regarding the use of internal "resistance" characteristics as a battery condition measurement. The interest reflects the desire for simple electronic means to replace discharge testing as a practical determination of residual battery capacity, particularly given the increased usage of seal lead-acid (SLA) batteries. The available techniques, which include AC impedance and conductance methods and momentary DC loading, all involve controlled current or voltage perturbations to determine a representation of the internal ohmic condition of the battery. Internal battery resistance has been proposed as a means to track battery life but greater interest lies in reported claims of specific correlation between cell impedance or conductance with battery capacity. More recent reports indicate that the currently available single-frequency internal ohmic determination techniques cannot, in general, provide unequivocal absolute battery capacity information. However, the techniques have been shown to have some merit as a comparative tool, and thus are useful in detecting early trends in rogue cells and

components with poor conduction integrity. In this sense, battery impedance, conductance or resistance measurements are now currently best viewed as an aid in assessment of battery state-of-health. Telstra is cautiously incorporating simple impedance measurements into various battery and power system maintenance routines. Advocacy of merit of any one determination method over the other is both of interest and a source of confusion to the end-user. For AC techniques, the selection of measurement frequency appears empirical in origin, drawn from very limited determinations of the frequency response of specific types of batteries. Furthermore, the published literature on fundamental impedance characteristics of lead-acid batteries is not unequivocal. Electrochemical impedance spectroscopy has been used in studies of electrode and plate behaviour during charging and discharging, but there has been only limited application to the near equilibrium condition for lead-acid batteries on float duty. The *ohmic* response of the battery depends on the measurement frequency and the state of the battery and has been reported to be affected, to varying degrees, by many fundamental cell characteristics, including cell design temperature and capacity. An understanding of the behaviour of lead-acid batteries on float is of paramount importance for stand-by applications. The frequency response of lead-acid batteries is important in determining the relative merits of various AC perturbation techniques currently used to probe the state-of-health of lead-acid batteries on standby duty.

1.1 Objectives of the Project

The objectives of the project are:

- 1.) To study the characteristic and operation of battery impedance.
- 2.) To Analyze the operation of battery impedance.
- 3.) To develop a practical battery charger for battery impedance based on simulation parameters and outcomes.

1.2 Project Scope

The scopes of this project are as follows:

- 1.) Designing the battery charger circuit and discharge circuit
- 2.) Develop a Printed Circuit Board (PCB) based on the parameters during simulation

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this chapter, the basis theories of continuous battery impedance tester alongside the architecture of the circuit will be reviewed. The type of batteries, and technique are described.

2.2 Battery Charger

With technical knowledge, batteries can be charged manually with a power supply featuring user-adjustable voltage and current limiting. charge termination is not automated. To observe the state-of-charge according to voltage and current behaviors. Lower the charge voltage or disconnect the charge when the battery is full. Because of difficulties in detecting full charge with nickel-based batteries, It recommend only charging lead acid and Li-ion batteries manually.

Before connecting the battery, calculate the charge voltage according to the number of cells in series, and then set the desired voltage and current limit. To charge a 12-volt lead acid battery (six cells) to a voltage limit of 2.40V, set the voltage to 14.40V (6 x 2.40). Select the charge current according to battery size. For lead acid this is

between 10 and 30 percent of the rated capacity. A 10Ah battery at 30 percent charges at about 3A. Starter batteries charge at lower currents, and an 80Ah pack would charge at about 10 percent of the rating, or 8A. Higher currents are possible.

Observe the battery temperature, voltage and current during charge. Charge only at ambient temperatures in a well-ventilated room. Once the battery is fully charged and the current has dropped to three percent of the rated Ah, the charge is completed. Disconnect the charge. High self-discharge (soft electrical short) may prevent the current from going to the anticipated low current level when fully charged. Disconnect the charge also when the current has bottomed out and cannot go lower. Float charge for operational readiness, lower the charge voltage to about 2.25V/cell.

It can also use the power supply to equalize a lead acid battery by setting the charge voltage 10 percent higher than recommended. The time in overcharge is critical and must be carefully observed. When using the power supply to perform equalizing.

A power supply can also reverse sulfation but there is no guarantee of success. When applying a charge, a totally sulfated lead acid may draw very little current at first, and as the sulfation layer dissolves the current will gradually increase and increase the charge voltage above the recommended level, set the current limiting to the lowest practical value and observe the battery voltage.

Lithium-ion charges similarly to lead acid and use the power supply also but use extra caution. voltage threshold to 4.20V/cell and make certain that none of the cells connected in series exceeds this voltage. Full charge is reached when the cell(s) reach 4.20V/cell voltage and the current drops to three percent of the rated current, or has bottomed out and cannot go down further. Once fully charged, disconnect the battery. Never allow a cell to dwell at 4.20V for more than a few hours.

Full-charge detection is difficult to assess because the voltage signature varies with the applied charge current, use the temperature rise on a rapid charge as an indication for full charge. When charging at a low current, estimate the level of

remaining charge and calculate the charge time. An empty 2Ah NiMH will charge in three hours at 500mA. The trickle charge must be reduced to 0.05C.

2.3 Lead Acid Battery

Lead acid was the first rechargeable battery for commercial use. Despite its advanced age, the lead chemistry continues to be in wide use today, and there are good reasons for its popularity; lead acid is dependable and inexpensive on cost-per-watt base. There are few other batteries that deliver bulk power as cheaply as lead acid, and this makes the battery cost-effective for automobiles, golf cars, forklifts, marine and uninterruptible power supplies (UPS).

But lead acid has disadvantages; it is heavy and is less durable than nickel- and lithium-based systems when deep-cycled. A full discharge causes strain and each discharge/charge cycle permanently robs the battery of a small amount of capacity. This loss is small while the battery is in good operating condition, but the fading increases once the performance drops to half the nominal capacity. This wear-down characteristic applies to all batteries in various degrees.

Depending on the depth of discharge, lead acid for deep-cycle applications provides 200 to 300 discharge/charge cycles. The primary reasons for its relatively short cycle life are grid corrosion on the positive electrode, depletion of the active material and expansion of the positive plates. These changes are most prevalent at elevated operating temperatures and high-current discharges. Charging a lead acid battery is simple but the correct voltage limits must be observed, and here there are compromises. A high voltage limit improves performance but form grid corrosion on the positive plate. While sulfation can be reversed if serviced in time, corrosion is permanent.

Lead acid does not lend itself to fast charging and with most types, a full charge takes 14 to 16 hours. The battery must always be stored at full state-of-charge.

Low charge causes sulfation, a condition that robs the battery of performance. Adding carbon on the negative electrode reduces this problem but this lowers the specific energy.

Lead acid has a moderate life span and is not subject to memory as nickel-based systems are. Charge retention is best among rechargeable batteries. While NiCd loses approximately 40 percent of its stored energy in three months, lead acid self-discharges the same amount in one year. Lead acid work well at cold temperatures and is superior to lithium-ion when operating in subzero conditions.

2.3.1 Characteristics

They remain the technology of choice for automotive SLI (Starting, Lighting and Ignition) applications because they are robust, tolerant to abuse, tried and tested and because of their low cost. For higher power applications with intermittent loads however, Lead acid batteries are generally too big and heavy and they suffer from a shorter cycle life and typical usable power down to only 50% Depth of Discharge (DOD). Despite these shortcomings Lead acid batteries are still being specified for PowerNet applications (36 Volts 2 kWh capacity) because of the cost, but this is probably the limit of their applicability and NiMH and Li-Ion batteries are making inroads into this market. For higher voltages and cyclic loads other technologies are being explored.

Lead-acid batteries are composed of a Lead-dioxide cathode, a sponge metallic Lead anode and a Sulphuric acid solution electrolyte. This heavy metal element makes them toxic and improper disposal can be hazardous to the environment.

The cell voltage is 2 Volts

2.3.2 Discharge

During discharge, the lead dioxide (positive plate) and lead (negative plate) react with the electrolyte of sulfuric acid to create lead sulfate, water and energy.

2.3.3 Charge

During charging, the cycle is reversed: the lead sulfate and water are electrochemically converted to lead, lead oxide and sulfuric acid by an external electrical charging source.

2.3.4 Advantages

- 1.) Low cost.
- 2.) Reliable. Over 140 years of development.
- 3.) Robust. Tolerant to abuse.
- 4.) Tolerant to overcharging.
- 5.) Low internal impedance.
- 6.) Can deliver very high currents.
- 7.) Indefinite shelf life if stored without electrolyte. .
- 8.) Wide range of sizes and capacities available.
- 9.) Many suppliers world wide.
- 10.) The world's most recycled product.

2.3.5 Shortcomings

- 1.) Very heavy and bulky.
- 2.) Typical coulombic charge efficiency only 70% but can be as high as 85% to 90% for special designs.
- 3.) Danger of overheating during charging
- 4.) Not suitable for fast charging
- 5.) Typical cycle life 300 to 500 cycles .
- 6.) Must be stored in a charged state once the electrolyte has been introduced to avoid deterioration of the active chemicals.

Gassing is the production and release of bubbles of hydrogen and oxygen due to the breakdown of water in the electrolyte during the charging process, particularly due to excessive charging, causing loss of electrolyte. In large battery installations this can cause an explosive atmosphere in the battery room. Because of the loss of electrolyte, Lead acid batteries need regular topping up with water. Sealed batteries however are designed to retain and recombine these gases.

Sulphation may occur if a battery is stored for prolonged periods in a completely discharged state or very low state of charge, or if it is never fully charged, or if electrolyte has become abnormally low due to excessive water loss from overcharging and/or evaporation. Sulphation is the increase in internal resistance of the battery due to the formation of large lead sulphate crystals which are not readily reconverted back to lead, lead dioxide and sulphuric acid during re-charging. In extreme cases the large crystals may cause distortion and shorting of the plates. Sometimes sulphation can be corrected by charging very slowly (at low current) at a higher than normal voltage.

Shedding or loss of material from the plates may occur due to excessive charge rates or excessive cycling. The result is chunks of lead on the bottom of the cell, and actual holes in the plates for which there is no cure. This is more likely to occur in SLI batteries whose plates are composed of a Lead "sponge", similar in

appearance to a very fine foam sponge. This gives a very large surface area enabling high power handling, but if deep cycled, this sponge will quickly be consumed and fall to the bottom of the cells.

- 1.) Toxic chemicals
- 2.) Very heavy and bulky

Lead acid batteries can work down to temperatures below $-45\text{ }^{\circ}\text{C}$, however, like all batteries the discharge rate and effective capacity are reduced at low temperatures. In the case of Lead acid batteries the capacity falls by about 1% per degree for temperatures below $+20\text{ }^{\circ}\text{C}$ so that at the lowest temperatures cranking capacity is seriously impaired.

2.4 Decomposition of the Electrolyte

Cells with gelled electrolyte are prone to deterioration of the electrolyte and unexpected failure. Such cells are commonly used for emergency applications such as UPS back up in case of loss of mains power. So as not to be caught unawares by an unreliable battery in an emergency situation, it is advisable to incorporate some form of regular self test into the battery.

2.5 Charging

- 1.) Charge immediately after use.
- 2.) Lasts longer with partial discharges.
- 3.) Charging method: constant voltage followed by float charge.
- 4.) Fast charge not possible but charging time can be reduced using the V Taper charge control method.

2.6 Applications

- 1.) Automotive and traction applications.
- 2.) Standby/Back-up/Emergency power for electrical installations.
- 3.) Submarines
- 4.) UPS (Uninterruptible Power Supplies)
- 5.) Lighting
- 6.) High current drain applications.
- 7.) Sealed battery types available for use in portable equipment.

2.7 Costs

- 1.) Low cost
- 2.) Flooded lead acid cells are one of the least expensive sources of battery power available.
- 3.) Deep cycle cells may cost up to double the price of the equivalent flooded cells.

2.8 Varieties of Lead Acid Batteries

Over the years battery manufacturers have introduced a range of additives such as Calcium, Antimony and Selenium to improve various battery performance parameters. For the same reason, different cell and battery constructions have been developed to optimise various aspects of battery performance.

2.8.1 Lead Calcium Batteries

Lead acid batteries with electrodes modified by the addition of Calcium providing the following advantages:

- 1.) More resistant to corrosion, overcharging, gassing, water usage, and self-discharge, all of which shorten battery life.
- 2.) Larger electrolyte reserve area above the plates.
- 3.) Higher Cold Cranking Amp ratings.
- 4.) Little or No maintenance.

2.8.2 Lead Antimony Batteries

Lead acid batteries with electrodes modified by the addition of Antimony providing the following advantages:

- 1.) Improved mechanical strength of electrodes - important for EV and deep discharge applications
- 2.) Reduced internal heat and water loss due to gassing, however the water loss is still greater than the equivalent loss in Lead Calcium batteries.
- 3.) Longer service life than Calcium batteries.
- 4.) Easier to recharge when completely discharged.
- 5.) Lower cost.

Lead Antimony batteries have a higher self discharge rate of 2% to 10% per week compared with the 1% to 5% per month for Lead Calcium batteries.

2.8.3 Valve Regulated Lead Acid (VRLA) Batteries

This construction is designed to prevent electrolyte loss through evaporation, spillage and gassing and this in turn prolongs the life of the battery and eases maintenance. Instead of simple vent caps on the cells to let gas escape, VRLA have pressure valves that open only under extreme conditions. Valve-regulated batteries also need an electrolyte design that reduces gassing by impeding the release to the atmosphere of the oxygen and hydrogen generated by the galvanic action of the battery during charging. This usually involves a catalyst that causes the hydrogen and oxygen to recombine into water and is called a recombinant system. Because spillage of the acid electrolyte is eliminated the batteries are also safer.

2.8.4 AGM Absorbed Glass Mat Battery

Also known as Absorptive Glass Micro-Fibre

Used in VRLA batteries the Boron Silicate fibreglass mat which acts as the separator between the electrodes and absorbs the free electrolyte acting like a sponge. Its purpose is to promote recombination of the hydrogen and oxygen given off during the charging process. No silica gel is necessary. The fibreglass matt absorbs and immobilises the acid in the matt but keeps it in a liquid rather than a gel form. In this way the acid is more readily available to the plates allowing faster reactions between the acid and the plate material allowing higher charge/discharge rates as well as deep cycling.

This construction is very robust and able to withstand severe shock and vibration and the cells will not leak even if the case is cracked.

AGM batteries are also sometimes called "starved electrolyte" or "dry", because the fibreglass mat is only 95% saturated with Sulfuric acid and there is no excess liquid. Nearly all AGM batteries are sealed valve regulated "VRLA". AGM's have a very low self-discharge rate of from 1% to 3% per month

2.8.5 Gel Cell

This is an alternative recombinant technology to also used in VRLA batteries to promote recombination of the gases produced during charging. It also reduces the possibility of spillage of the electrolyte. Prone to damage if gassing is allowed to occur, hence charging rates may be limited. They must be charged at a slower rate (C/20) to prevent excess gas from damaging the cells. They cannot be fast charged on a conventional automotive charger or they may be permanently damaged.

2.8.6 SLI Batteries (Starting Lighting and Ignition)

This is the typical automotive battery application. Automotive batteries are designed to be fully charged when starting the car; after starting the vehicle, the lost charge, typically 2% to 5% of the charge, is replaced by the alternator and the battery remains fully charged. These batteries are not designed to be discharged below 50% Depth of Discharge (DOD) and discharging below these levels can damage the plates and shorten battery life.

2.8.7 Sealed Lead Acid

The first sealed, or maintenance-free, lead acid emerge in the mid-1970s. The engineers argued that the term “sealed lead acid” is a misnomer because no lead acid battery can be totally sealed. This is true and battery designers added a valve to control venting of gases during stressful charge and rapid discharge. Rather than submerging the plates in a liquid, the electrolyte is impregnated into a moistened separator, a design that resembles nickel- and lithium-bases system. This enables to operate the battery in any physical orientation without leakage.